Predicting the Distribution and Properties of Buried Submarine
Topography on Continental Shelves

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LONG-TERM GOALS

The long-term goal of the Geoclutter modeling project is to predict the distribution and properties of buried channels that may be responsible for geoclutter on continental margins of interest.

OBJECTIVES

The overall objectives of our project are 1) to determine the characteristics of channel features that can form when the present continental shelf subject to sea-level variations and 2) to determine whether these features would be buried when sea-level returned to its present position and, if so, how deeply. During FY03, our objectives have been to complete our analysis of fluvial incision and deltaic deposition, to incorporate and test coastal and shelf modules into the land/sea-scape evolution, and to begin calibrating the fluvial incision model using Atlantic coastal-plain fluvial erosional histories.

APPROACH

Our approach is to develop numerical simulation models of landscape evolution and shelf sediment transport to investigate the development of topography on the shelf during sea-level low stands and the burial of that topography during high sea-level conditions. Our model is based on Alan Howard's drainage basin evolution model, DeLiM. Alan Howard and Sergio Fagherazzi (now at FSU) have adapted, tested, and applied the landscape evolution model to coastal plain settings and exposed continental shelves. Sergio Fagherazzi has developed and implemented coastal modules and Patricia Wiberg has developed shelf sediment transport modules for the land/sea-scape evolution model.

WORK COMPLETED

1. Characterized fluvial incision and deltaic deposition for a range of shelf and sea-level configurations. [Fagherazzi et al, submitted]
2. Acquired geological and geomorphological coastal plain data for calibration of the channel incision model, especially with respect to effects of vegetation.

3. Formulated a 2-dimensional coastal evolution model to track the position of the shoreline and barrier islands as sea-level varies. [Fagherazzi et al., 2003]
4. Implemented a coastal processes module in the land/seascape evolution model.
5. Implemented a diffusive shelf sediment transport formulation in a 2-D shelf evolution model.
6. Identified decadal-century scale variations in wave climate that modulate sediment transport on the shelf.

RESULTS

Characterization of fluvial incision: During the past year modeling with an enhanced version of the DeLiM landscape evolution model [*Howard*, 1994; 1997] was used to investigate fluvial dissection and deltaic deposition on continental shelves using both actual and hypothetical sea-level curves for the last 120,000 years. As reported in *Fagherazzi et al*., [submitted], dendritic valleys up to 40-m deep are predicted to erode during this period. Detailed soundings off the New Jersey coast supported by the Geoclutter program revealed a buried dendritic channel network with valleys up to 30 m deep [*J. P. Walsh, personal communication*, 2003]. This simulation modeling also indicated that major upland rivers create broad, shallow deltas on the continental shelf during sea level regression. Avulsions are common during short intervals of sea-level rise superimposed within the 120,000 year regressive cycle. The deltaic platforms experience little fluvial incision even when exposed by further sea level fall, with the exception of the single incised channel of the main river.

Calibration of the channel incision model for vegetation influences: The degree and rapidity of vegetation growth is a major issue when simulating fluvial incision on continental shelves that are exposed during sea level lowering. Vegetation is very effective at reducing both runoff volumes and surface erosion. Vegetation effects can be parameterized in the simulation model through a critical shear stress required for onset of fluvial erosion as well as changes in runoff yield. Two end-members can serve to bracket possible vegetation influences. In the absence of vegetation, coastal plain sediments are highly erodible, and the study of badland development on such sediments upon vegetation removal [*Howard and Kerby*, 1983] allowed us to derive model parameters for this case. The long-term (Cenozoic) dissection of the strongly vegetated Atlantic Coastal Plain is the other end-member. We have identified a site on the estuarine portion of the Potomac River (Colonial Beach South Quadrangle, Virginia) that has a well-known erosional history based upon detailed geomorphic mapping by Wayne Newell of the U.S. Geological Survey. We have selected this quadrangle as a basis for calibrating the simulation model for the case of dense vegetation, and we have developed a collaborative relationship with Mr. Newell. Four surfaces of different age and differing degree of incision are present within the quadrangle. The oldest, highly dissected surface is of Pliocene age, whereas the lower, less dissected surfaces formed during successive Pleistocene interglacial epochs. Proper selection of model parameters should permit simulation of the differing degrees of dissection of the four surfaces.

Coastal evolution model: We developed a model to study the formation and evolution of barrier islands. The two-dimensional, cross-shore formulation is necessary to correctly describe the complexity of the processes responsible for barrier islands formation. Results will be extended in three dimensions and incorporated in the DeLiM model, as a part of the coastal processes module. The model is based on the conservation of equilibrium cross shore profile (Dean's profile), on the translation of the beach profile as a consequence of sea level oscillations (Bruun's rule), and on back barrier deposition dictated by storm overwash. Comparisons between volume of sediments mobilized during storms and rate of sea-level rise enables us to determine whether a barrier island drowns or survives marine transgression. Moreover simulations show that barrier islands develop during sea-level transgression at the coastline location, whereas their formation is unlikely during marine regression.

Coastal Processes Module: A first version of the coastal processes module has been implemented in the DeLiM model. The implementation is based on the conservation of a cross-shore profile. Sediment volumes out of equilibrium are reworked by waves and distributed along the coast. We utilize an asymmetric diffusive equation that can be calibrated with the local wave climate. During transgression simulations show that sediment redistribution by waves partly deletes the shelf topography and the incised channels (Figure 1).

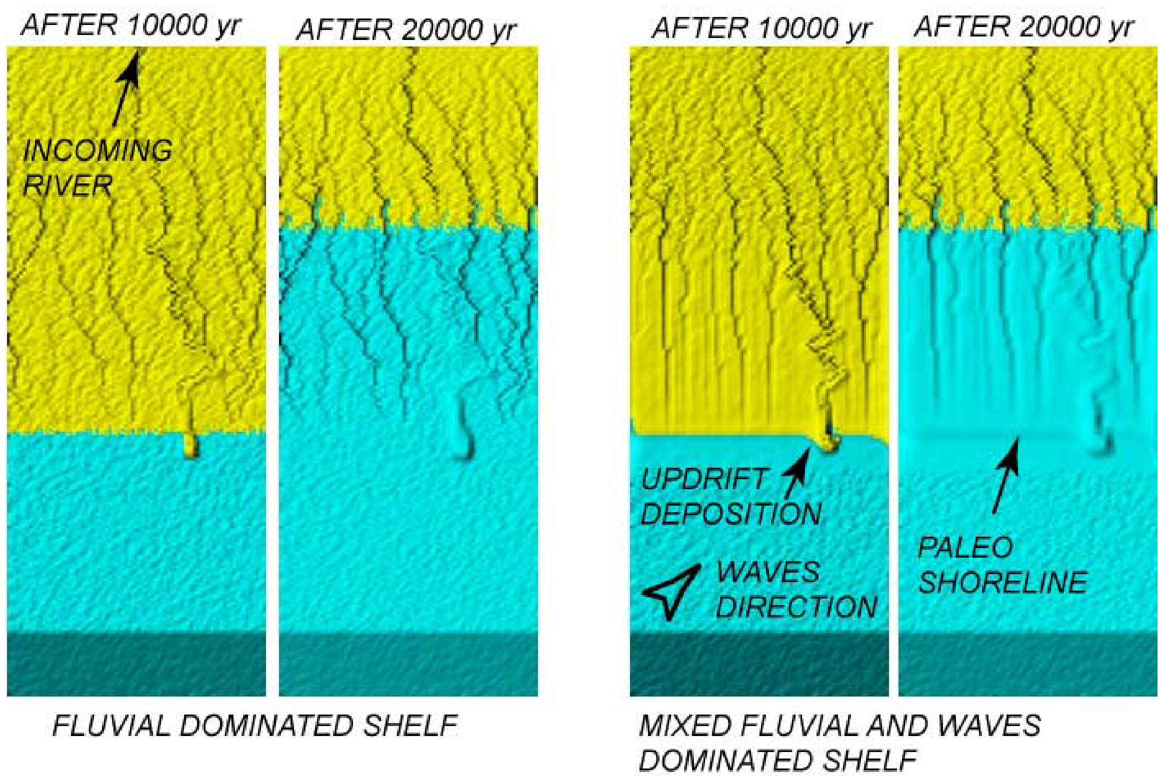

Figure 1: Model simulations with and without the coastal processes module. Sea level falls 50m during the first 10 kyr and then reaches the original elevation after 20 kyr. Incoming waves modify the shape of the river delta, with updrift deposition and downdrift erosion and rework shelf sediments to smooth the topography. Channels become more regular and are partially erased during transgression. A paleoshoreline is located at the lowest ocean elevation at the end of the simulation.

Diffusive shelf sediment transport calculations: The cross-shelf sediment diffusion coefficients developed previously in this Geoclutter study from shelf wave, current and sediment data were used to characterize shelf sediment transport fluxes and resulting changes in seabed elevation in a simple, 2-D shelf evolution model. The purpose was to determine the equilibrium profile consistent with the calculated diffusion coefficients and whether calculated rates of bed elevation change across the shelf were realistic. The implementation highlighted a problem not only in this model, but one found in other shelf evolution models: bed erosion is strongly dependent on the amount of sediment assumed to be available for transport. In the cross-shelf model used here, diffusion acts on an active layer thickness that decreases with depth offshore. The frequency with which the active layer is refreshed strongly influences erosion and deposition rates. For example the model indicates that a channel on the shelf will almost fill over a period of 5 years if the active layer is refreshed every 2 weeks, whereas a relatively small amount of deposition is calculated when the active layer is refreshed once a year (Figure 2.). A better understanding of the controls on active layer depth and renewal will be important for long-term models of shelf evolution that include effects of shelf transport.

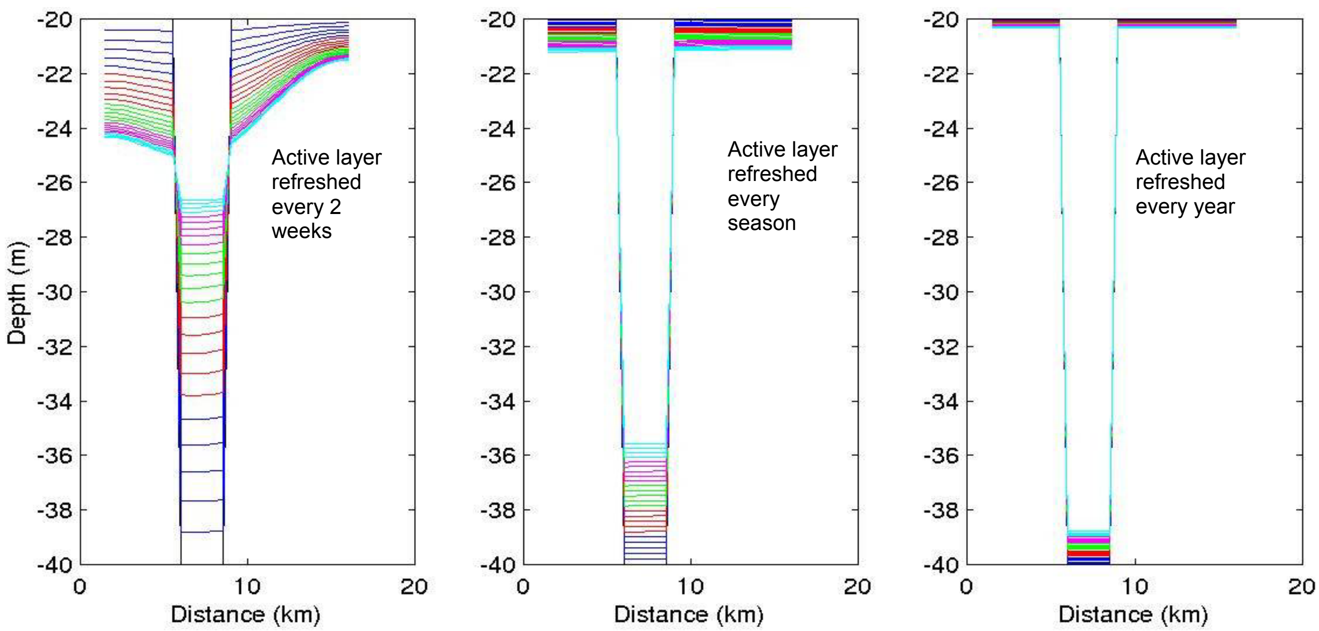

Figure 3. Calculations of evolution of a 20-m-deep channel on the shelf using a simple 2D cross-shelf model in which sediment flux is determined from data-based estimates of wave and current-induced sediment diffusion and 3 frequencies for the reestablishment of an active layer on the seabed: a) every 2 weeks; b) every season; and c) every year. Each color represents 1 year in the 5-year simulation.

Decadal-century-scale variation in wave climate affecting shelf sediment transport: Analysis of sea-level pressure and ocean wave data suggest that the wave orbital velocities (u_b) along the Pacific coast of North American are related to atmospheric conditions over the North Pacific. Figure 3 shows the percentage of days in the cold season (October through March) during which u_b exceeded the given threshold values at the location of NDBC buoy 46022 (40º43’12’’N, 124º31’12’’W). This figure also contains the time series for the first principal component (PC) of the North Pacific sea-level pressure (SLP) field as calculated from the NCEP reanalysis data. With a few deviations, the changes in the frequency of u_b crossing each threshold correspond well with temporal variations in the first PC of SLP.

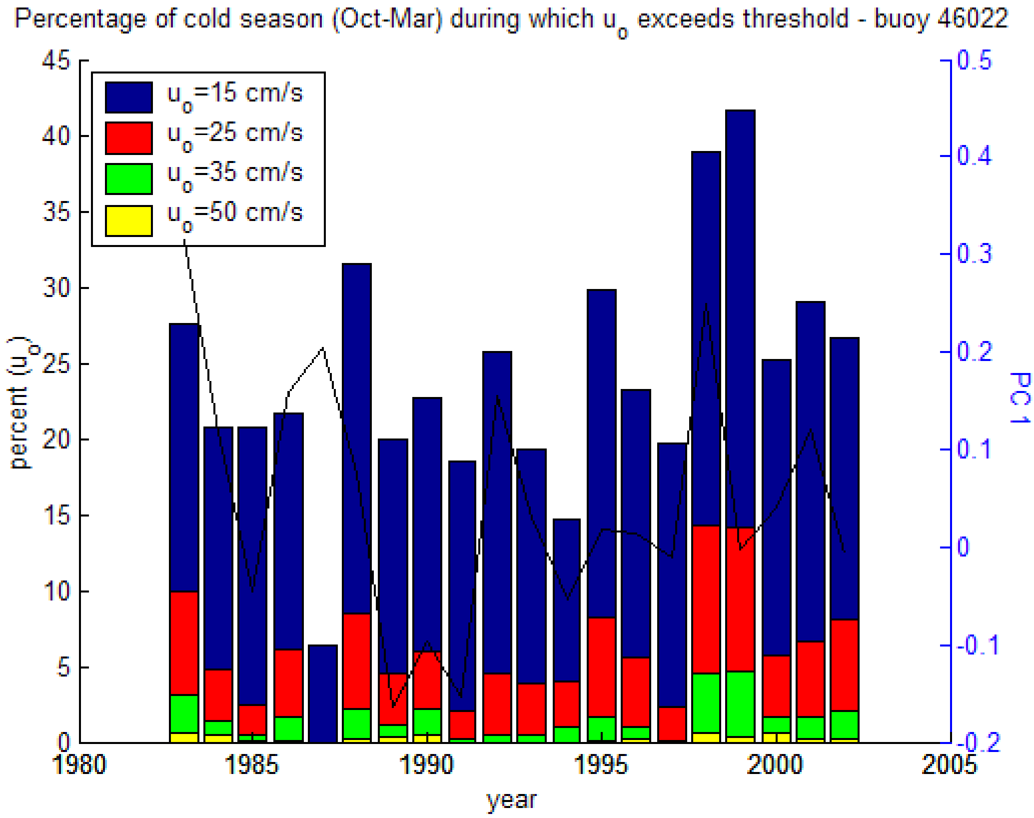

Figure 3. Bars show the percentage of days in the cold season (October through March) during which u_b exceeded each of the threshold values at a depth of 80m for NDBC buoy 46022. The black line is the first principal component of NCEP reanalysis sea-level pressure over the North Pacific.

We selected out the 1993-1994 and 1997-1998 cold seasons as years during which u_b was anomalously low and high (respectively). Corresponding SLP was anomalously high in the region around the coast during the 1993-1994 cold season. Additionally, during the 1997-1998 cold season – a season with a higher than average frequency of u_b crossing each threshold – the SLP field is anomalously low in the area off the coast of North America. The principles governing wave generation show that the regional-scale atmospheric conditions will influence coastal waves, and that anomalously low pressures in the North Pacific will lead to higher values of u_b. Therefore we are relating variations in SLP to spatial and temporal variations in wave climate on the shelf, which in turn modulates sediment transport as quantified e.g., using a wave-current diffusion coefficient as described above.

IMPACT/APPLICATION

The models we are developing will provide quantitative information about channel depth, geometry, and fill for use in algorithms to reduce acoustic clutter associated with buried channels on the continental shelf.

RELATED PROJECTS

The Detachment Limited Model we have developed for the Geoclutter program has been applied to the Adriatic shelf (Italy) to simulate the development of rivers and related incisions during sea-level cycles as part of the EuroSTRATAFORM program.

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